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OUTLINE
OF THE
GEOLOGY OF LONG ISLAND IN ITS RELATIONS TO THE PUBLIC WATER SUPPLY

BY

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OUTLINE OF THE GEOLOGY OF LONG ISLAND IN ITS RELATIONS TO THE PUBLIC WATER SUPPLIES.

BY W. O. CROSBY.[1]

GEOLOGICAL FORMATIONS OF LONG ISLAND.

ALTHOUGH our knowledge of the geological structure of Long Island is still, in certain directions, very incomplete, the main features are now pretty well determined. We know that the island consists chiefly, at least, of the following formations, commencing with the lowest and oldest:

First, the primitive or crystalline rocks (granite, gneiss, schist, etc.). These are a southward continuation of the formations of southern New York and Connecticut; and they may safely be assumed to underlie the entire area of Long Island, although actually exposed to observation only on the extreme northwest corner of the island.

Second, the Cretaceous formation continued northeastward from New Jersey, and consisting of clays and sands in many alternations with occasional beds of gravel, especially near the base, which have proved in New Jersey to be important water-horizons. The Cretaceous strata, which are 500 feet or more in thickness, slope gently seaward and, so far as known, rest directly upon the crystalline rocks, although it is not improbable that in the central and eastern parts of the island Jurassic and Triassic strata intervene. Only the Lower Cretaceous appears to be represented on Long Island now, the Upper Cretaceous, which also contains several good artesian sources in New Jersey, having been, apparently, worn off from the Long Island area before and during the formation of the Tertiary strata which overlie it.

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[1] This sketch of that part of the geology of Long Island having a bearing upon the public water supplies, has been prepared at the request and with the coöperation of Mr. John R. Freeman, in connection with his investigation of the water supply of Greater New York, and is published by his permission.

The writer's opportunities for original observations on the geology of Long Island have been comparatively limited, and this summary, especially as regards the statements of fact, is, therefore, to a large extent a compilation from the writings of other students in this field, including especially Bryson, Dana, Hollick, Lewis, Merrill, Ries, Upham and Woolman.

Third, the Neocene Tertiary formation, including: (a) the Chesapeake division, composed of the gray gravel, from 10 to 100 feet thick, which is, in general, an important water-horizon, and the great bed of blue clay with a normal thickness of 100 feet, overlying the gray gravel and forming with it one continuous formation; and (b) the heavy bed of yellow gravel, 50 to 100 feet thick, which now forms the surface over a large part of the island, and is by far the most important reservoir of the ground-water.

Fourth, the terminal moraine of the great ice-sheet or continental glacier of northeastern North America, an irregular ridge composed chiefly of unstratified bowlder-clay, or glacial drift, built upon the elevated northern edge of the island, and sometimes called the "backbone" of Long Island.

THE WATER-BEARING STRATA.

The water-bearing formations or horizons of Long Island are practically limited to the yellow gravel above the blue clay, the gray gravel below it, and certain layers of gravel and sand in the underlying Cretaceous formation; and, as will be set forth clearly in what follows, these are named here in the order of their value and availability. The yellow gravel, which receives and holds almost the entire rainfall of the island, ranks first in importance; while the gray gravel and the Cretaceous gravels, being cut off from any possible influx of water from the mainland of Connecticut or New York, can afford but a limited and uncertain supply, which is likely to be stale or mineralized, and, if heavily drawn upon, to become brackish.

GEOLOGICAL HISTORY OF LONG ISLAND.

In order to understand the arrangement and succession of the strata, and to estimate the probability of copious and permanent supplies of water of good quality for domestic use being found in any particular stratum, we must study the history of the formations and the conditions under which their component strata were laid down.

Origin of the Cretaceous Strata. — In late Jurassic and early Cretaceous times, southern New England stood higher than now; and the Connecticut River, following the belt of red (Triassic) sandstone and shale southward to the present site of New Haven, continued seaward across a lowland which is now occupied in part by Long Island.

During Jurassic and Cretaceous times this region was being slowly base-levelled or reduced to the condition of a peneplain, partly through the agency of marine erosion during a slow subsidence of the land; and the Cretaceous sediments, chiefly clays and sands, were deposited to a thickness of 500 and possibly 1,000 feet over the site of Long Island, reaching far inland over a large part of southern New England. There were, doubtless, many oscillations of level. During movements of subsidence, the sea, actively wearing away the sinking land, formed banks of gravel and sand near the shore, and deposited the clays and finest sands farther out in deep, still water; then, during movements of elevation, the gravel and coarse sand were swept seaward and spread over the clays; and thus, by many repetitions of this process, the alternating series of coarse and fine sediments was gradually built up.

The land was then slowly elevated, exposing the newly formed Cretaceous sediments as a broad, smooth coastal plain across which the sluggish streams wandered seaward without regard to their deeply buried original channels. It thus happened that the Connecticut, below Middletown, abandoned its natural course as determined by the north-south belt of Triassic strata and wandered off to the southeast, reaching the ocean across what is now the east end of Long Island, west of Montauk Point. The Housatonic experienced a similar diversion to the southeast; but the Hudson adhered to its original north-south course to its present mouth at the Narrows, whence its channel may be traced by soundings southeastward across the sea-bottom for a hundred miles. As the Cretaceous strata were gradually worn away, the streams cut down through them into the crystalline rocks; and they necessarily held to these new courses after the Cretaceous beds had been completely removed from what is now the mainland. This explains the fact that while north of Middletown the Connecticut meanders through a wide north-south sandstone valley, south of Middletown it abruptly leaves this valley and flows through a narrow gorge in the crystalline peneplain on which it was superposed in a purely accidental or fortuitous manner by the wearing down of the Cretaceous plain across which it had pursued the most direct seaward course.

Origin of the Tertiary Strata, including the Gray Gravel, the Blue Clay, and the Yellow Gravel. — The erosion of the Cretaceous formation was followed by a second slow but less extensive submergence of the land, during which were deposited the Tertiary strata. As the Tertiary sea slowly encroached upon the land, the Cretaceous strata remaining above sea-level were worked over by the waves, and the coarse material sorted out and deposited always near the advancing shore to form a basement bed of coarse, dark gray gravel and sand, while the clayey element was deposited farther out in deep, still water to make the blue clay formation overlying the dark gray gravel and sand. This dark gravel and sand formation, which, although an important water-horizon, is more or less interstratified with clay, is commonly 10 to 20 feet thick, but sometimes much thicker (50 to 100 feet) where it fills hollows in the eroded Cretaceous beds. The overlying blue clay is normally at least 100 feet thick, but in some places is much thinner, where it has been eroded before the deposition over it of the great mass of iron-stained quartz-gravel, the formation of which is explained in the next paragraph.

Finally the shore-line, in its northward progress, reached the hard crystalline rocks (granite, gneiss and schist) of the recently denuded Cretaceous peneplain of southern Connecticut; and the subsidence of the land beneath the waves was so slow and long continued, that the sea, coöperating with subaerial agencies (rain, frost, streams, etc.), had time to develop, for a breadth of 5 to 10 miles, a new (Tertiary) peneplain several hundred feet lower than the Cretaceous peneplain. During this slow process of peneplanation (wearing down of the land to an approximately plane surface) the sea also had time to reduce all the constituents of the crystalline rocks, except the quartz, to fine sand and clay, which were swept seaward by the waves and currents and deposited in deep water remote from the land; while the resistant quartz, in the form of well-rounded pebbles or gravel, was left near the shore, covering the newly-formed Tertiary peneplain. The gravel is thus essentially a residuary product of long-continued marine erosion, although it probably consists in part also of the worked-over Cretaceous gravels, which had been similarly derived from the crystalline rocks during the development of the Cretaceous peneplain and sediments.

This slow subsidence of the land was probably followed by an oscillation (elevation and subsidence) during which the blue clay suffered some erosion, and the great mass of quartz-gravel was washed seaward and spread over the eroded surface of the Tertiary blue clay as we now find it, in a bed having a normal thickness of about 75 to

100 feet, but attaining a greater thickness up to 300 feet, where it fills hollows or valleys eroded in the blue clay. This immense body of residuary quartz-gravel which is now the principal surface formation of Long Island, covering all the plain country both north and south of the terminal moraine, and which, by virtue of its superficial position and open (pervious) structure, is also the chief reservoir of the ground-waters, has become more or less stained with iron oxide, and is known by geologists as the yellow gravel. From the western end of Long Island the yellow gravel extends southwestward across Staten Island and the lowlands of New Jersey; and it is to be regarded as one of the most important as well as one of the latest formations of the Atlantic seaboard. It belongs chiefly, at least, to the Lafayette division of the Neocene period; while the underlying blue clay and gray gravel may be referred, provisionally, to the Chesapeake division of the Neocene.

Origin of the Terminal Moraine of Long Island. — Finally came the important and long-continued elevation of the land which ushered in the great Ice Age, the total upward movement amounting, according to the evidence of the deep submarine channel of the Hudson River, to at least 3,000 feet. During this elevation of the land, the lateral tributaries of the Connecticut, Housatonic, etc., wore back the northern or landward edge of the bed of yellow gravel and the underlying clays and sands, developing the abrupt slope or escarpment which now forms the northern edge of Long Island, — a typical cuesta overlooking the inner lowland which is now occupied by Long Island Sound.

As the land gained in height, the great ice-sheet slowly crossed the lowland, pushed against the cuesta, or northward-facing escarpment, distorting the strata; and finally surmounting the cuesta, built upon its crest the terminal moraine, which is largely composed of yellow gravel, clay and sand scraped up by the ice from the northern face of the ridge.

Description of the Terminal Moraine. — The moraine is, in places, several miles wide, and ranges in height from nothing to about 200 feet, presenting, where most typically developed, a strongly undulating surface — a disorderly grouping of winding ridges, hummocks and hollows, with many closed basins or "kettles."

The moraine, known commonly as the "backbone" of Long Island, is most normally developed toward the west end of the island, in

Brooklyn, where the till, or bowlder-clay, attains its maximum thickness of 150 to 200 feet, and thence eastward to Roslyn, or as far as the Sound is narrow. As the Sound widens eastward we find that the proportion of material which was brought across from the mainland by the ice-sheet steadily diminishes; and the moraine is composed in increasing proportion of sand and gravel scraped up and pushed up by the ice from the northern or scarp face of the cuesta, with occasional bowlders of granite, gneiss, etc., sometimes of great size (10 to 30 feet in diameter), resting upon it.

The deep, fiord-like indentations or bays of the northern coast all have a south-southeast trend, coinciding with the direction of glacial movement; and there can be no doubt that they were formed chiefly, if not wholly, by the scouring action and thrust of thick lobes of the ice-sheet. It is of special interest in this connection to note that the highest and broadest parts of the moraine lie in the trend of these fiords, or just where the theory that the fiords were plowed out by the ice would lead us to expect a special accumulation of material. Thus, south-southeast of the indentations of the coast named below, we find the corresponding hills.

Hempstead Harbor, Harbor Hill, 384 feet high.

Cold Spring Harbor, Janes Hill, 383 feet high, and other hills above 300 feet, including the ridge extending south to Bethpage.

Huntington Bay, Dix and Comac Hills, 250 feet.

Smithtown Harbor, Mt. Pleasant, 200 feet.

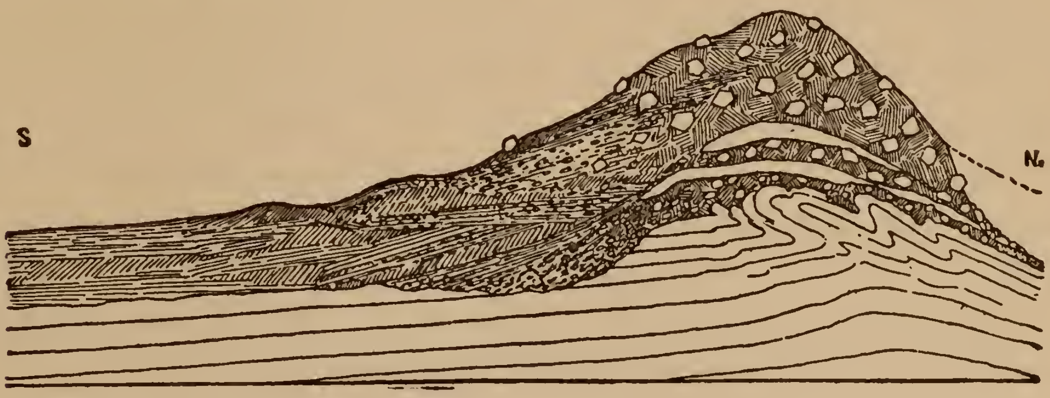
Stony Brook Harbor, Bald Hills, 200 feet.

Port Jefferson Harbor, Reuland's Hill, 340 feet.

Wading River, Terry's Hill, 175 feet.

That the clay ridge or ridges extending south-southeast from Cold Spring and Huntington Harbors to Bethpage and West Deer Park are due to glacial thrust appears reasonably certain, the overlying gravel having been largely scraped off by the movement of the ice.

The southern limit of the ice action is very indefinite, being marked chiefly by scattering bowlders. While the ice-sheet was building its moraine, the water resulting from its melting partly escaped to the southward, washing more or less sand and gravel down across the northern edge of the broad plain of yellow gravel extending from the moraine to the southern coast. This over-wash material, or apron-plain, is probably relatively unimportant, and we may regard the main body of the gravel forming this great plain as preglacial, and as extending continuously through the morainal tract to the northern coast. In fact, the moraine itself is chiefly due to the mashing and scraping up of the gravel, as previously stated. The accompanying diagrammatic section by Hollick shows the general relations of the moraine to the underlying formations, and the highly disturbed and crumpled condition of the latter.



DIAGRAMMATIC SECTION SHOWING THE GENERAL RELATIONS OF THE MORAINE TO THE UNDERLYING FORMATIONS. After Hollick.

Post-glacial Deposits and Changes. — Since the recession of the ice-sheet, the land has subsided until the sea has covered the inner lowland, forming Long Island Sound; and it is supposed that this part of the coast, after one or more oscillations, is still slowly sinking. By virtue of the monoclinal structure, the strata all dipping to the south 10 to 25 feet per mile, the northern coast of the island is bold and sharply defined, while the southern coast is shifting and indefinite, and bordered by a continuous line of barrier beach.

The recent studies of glacialists afford fairly accordant indications as to the length of post-glacial time, the most probable estimate being that something like 10,000 years have elapsed since the final disappearance of the great ice-sheet from the latitude of Long Island. The only noteworthy changes in the geological formations of Long Island during this post-glacial period are the construction by the waves of the barrier beach along the southern coast, the erosion of the headlands of the northern coast, and the partial silting up of the bays, harbors, and inlets of both coasts. The extent of subærial erosion during the same period has been almost inappreciable, owing largely, as explained in the next paragraph, to the high porosity of the yellow gravel, which prevents the formation of surface streams.

The preservation of the integrity of the plain of yellow gravel south of the moraine and forming from one-half to two-thirds of the entire area of the island, through glacial and post-glacial times is undoubtedly due to the well assorted and consequently highly porous character of the material, which absorbs the rain-water and prevents the formation of surface streams above the general water-level of the plain. Where the gravel is so situated that it can be undermined by the washing away of the underlying clay, the gravel must, of course, suffer erosion with the clay. But over its upper surface the gravel is almost impregnable, so that its geological age is out of proportion to the slight amount of erosion which it exhibits.

The yellow gravel must have been, when first deposited, white or non-ferruginous, for the mechanical action of the waves would soon remove the pellicle of iron oxide which now invests each pebble; and the present iron-stained condition of the gravel is an index of its porosity, being clearly due to the percolation and evaporation of meteoric water, probably at a time when the land stood higher than now, and the water-level may have sunk in dry seasons to the bottom of the gravel, giving the atmosphere a chance to penetrate and peroxidize the dissolved iron, one source of which is, perhaps, to be found in the pyritiferous blue clay, especially where it has been scraped up to form a part of the terminal moraine.

Summary of the Geological Structure and Correlation of the Strata. — Regarding Long Island as it now exists, we find that it is a sloping plain from 10 to 20 miles wide, and from 100 to 200 feet high along its deeply indented northern edge. On this high edge is built the terminal moraine, adding from zero to 200 feet to the height. The crystalline rocks are exposed only on the extreme northwest corner of the island, in Long Island City and the immediate vicinity of Hell Gate. The surface of the crystalline rocks slopes to the southeast, and probably at a somewhat uniform rate, gaining a depth of about 550 feet below sea-level in the first five miles, as shown by the artesian well at Woodhaven.

Upon this crystalline floor rests the great thickness of Cretaceous sands and clays. The Cretaceous outcrop is very largely covered by the terminal moraine, but its southeastern border is a line extending from Bay Ridge, on the Narrows, to Eaton's Neck, on the shore of the Sound. The outcrop of the bed of dark gray sand and gravel separating the Cretaceous and Tertiary, and forming the lower water-horizon, is quite clearly indicated by the east-west indentations of the shores of the northern bays, from Manhasset to Eaton's Neck. The intervening headlands or necks are thus more or less completely divided, the Cretaceous clays outcropping on the northern member, and the Tertiary clays on the southern member of each neck. Beyond Eaton's Neck, however, the Cretaceous clays are wanting; and in the vicinity of Port Jefferson and on Crane's Neck we have only the Tertiary clays. The southern border of the Tertiary clay outcrop passes near the head of each bay or harbor. In consequence, however, of the disturbance of the strata due to the pressure and thrust of the ice-sheet, the Tertiary clay also outcrops south of this line, at East Williston, Bethpage, and West Deer Park.

Near Brooklyn the normal dip of the strata is southeast, and farther east it is south-southeast. The dip evidently exceeds the slope of the broad coastal plain (10 to 20 feet per mile), averaging perhaps 25 feet per mile. From a comparison of the Woodhaven and Barren Island artesian wells, Woolman concludes that the normal dip in that part of the field is south-southeast, about 45 feet per mile.

The Cretaceous formation is a complex of coarse and fine sediments — a constant alternation of sand and clay, with some gravel, through a great thickness. The blue clay is in part distinctly carbonaceous (black) and characterized by carbonized wood, or lignite, and both disseminated and nodular sulphide of iron (marcasite). Superficially, also, the clay is often oxidized to buff and brown tints.

The fact that on Long Island the outcrops of the Cretaceous and Tertiary strata are almost completely covered by the terminal moraine, and the further facts that these formations are unlithified, and that in the morainal belt they have been very extensively disturbed and displaced by the pressure, thrust and abrasive action of the ice-sheet, have baffled all attempts to unravel the details of the stratigraphy and obtain the data for a satisfactory correlation with the formations of New Jersey by surface observations. It is obvious that for the solution of this problem we must depend chiefly upon the records of artesian wells and other borings, and these are as yet insufficient for the purpose. Greensands, which are such a prominent feature of the Upper Cretaceous of New Jersey, are conspicuous by their absence on Long Island. This fact, with others of like import, and the absence of distinctive fossils, indicate that the Upper Cretaceous, at least above the Clay Marls, is, in the main, unrepresented on Long Island. This may be due to non-deposition, but quite as likely to the erosion which preceded and attended the advent of the Tertiary strata;

for the borings indicate very plainly a strong erosion unconformity between the Cretaceous and Tertiary.

That the blue clay, with the intercalated and underlying sands and gravels, represents the Chesapeake division of the Neocene Tertiary is reasonably certain; but it does not appear that the diatomaceous phase of the clay is well or distinctly developed on Long Island. The yellow gravel, which rests in entire unconformity upon all the older formations, may, in the main, at least, be referred with confidence, as in New Jersey, to the Lafayette division of the Neocene; while the modified drift south of the moraine, consisting to a large extent of the yellow gravel, and not always readily distinguishable from it, but with incorporated subangular pebbles of granite and gneiss and other glacial detritus, is clearly the equivalent of the Columbia division of the Pleistocene.

RELATIONS OF THE GROUND–WATER TO THE GEOLOGICAL STRUCTURE.

WATER-BEARING FORMATIONS OF THE ATLANTIC SEABOARD.[1]

Age.	Formation.	Thickness.
PLEISTOCENE	Glacial drift, including the terminal moraine. Columbia, or glacial gravel south of the moraine.	
NEOCENE	Lafayette — Yellow Gravel. Chesapeake — Marls, clays and sands, and the great Diatom bed.	
EOCENE	Shark River — Part of Upper Marl bed.	12 feet.
UPPER CRETACEOUS .	Manasquan — Part of Upper Marl bed.	65 feet.
	Rancocas — Middle Marl bed.	50 feet.
	Red Sand.	50 feet.
	Monmouth — Lower Marl bed.	100 feet.
	Matawan — Clay Marls.	275 feet.
LOWER CRETACEOUS .	Raritan — Plastic Clay.	347 feet.
JURA-TRIAS	Red shales and sandstones, with trap sheets.	

[1] Compiled from the Reports of the Geological Survey of New Jersey.

Principal Water-Horizons of New Jersey.[1]

First Horizon. — *The Raritan Group.* This may be defined as a group of two or three horizons in heavy gravel and cobble strata near the base of the Plastic Clays, which clays are variously colored white, yellow and red, or they are mottled in all these colors. The color of the water-yielding gravels may be defined as a yellowish white in contrast with those of the next higher horizon, which are of a bluish white.

Second. — *The Sewell Horizon.* At the top of the Plastic Clays and base of the Clay Marls. The water-bearing gravels are often very coarse. Their color is a bluish white in contrast with those of the first group.

Third. — *The Woodbury-Wenonah Horizon.* This horizon is near the base of the Clay Marls. In the region about Woodbury, the depths of the various wells seem somewhat too irregular to indicate a well-defined water-bearing sand; and this horizon is there probably distributed through a considerable thickness of laminated sands; while in the neighborhood of Wenonah the horizon, according to our present information, is not so thick, and yet appears to be more decidedly a single sand bed.

Fourth. — *The Cropwell Horizon.* This horizon is midway in the Clay Marl or Matawan formation. It is not, so far as yet known, more than a few feet thick, but yields mostly a satisfactory quality of water, often doing so at points where the water from the next higher horizon, as is occasionally the case, proves somewhat too highly charged with iron.

Fifth. — *The Marlton Horizon.* At the top of the Clay Marls and base of the true greensand marl series, which consists of the Upper, Middle and Lower Marl beds.

Sixth. — *The Lindenwold Horizon.* A few wells have been developed in this horizon, which is within the Bryozoan limesands next above the Middle Marl bed.

Seventh. — *The 950-foot Atlantic City Horizon.* This horizon may be regarded as one not yet thoroughly defined. The only wells so far known that can draw from it, are one each at Winslow and Berkeley, and one to the 950-foot horizon at Atlantic City. This horizon is *probably* at the base of the Neocene and top of the Eocene beds.

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[1] Compiled from the Reports of the Geological Survey of New Jersey.

EIGHTH. — *The 800-foot Atlantic City Horizon.* About 150 feet higher than the preceding one, and about 125 feet below the base of the great 300 to 400-foot Diatom bed in the Neocene.

NINTH. — *The 700-foot Atlantic City Horizon.* About 100 feet or more higher than the fifth, and a little below the base of the great Diatom bed in the Neocene.

Minor horizons yielding much less water than those above listed occur above the ninth or 700-foot Atlantic City horizon, in or in close connection with, the great Diatom clay bed of the Chesapeake division of the Neocene strata.

TENTH. — *The Yellow Gravel Horizon.* Of very exceptional importance on Long Island.

Passing along the coast northward from Barnegat, New Jersey, some of the upper of these horizons would not be met with at all points, but southward from Barnegat if a well were drilled anywhere sufficiently deep, it would probably find all of them, unless perhaps a few of the thinner ones which have as yet only been developed in the central and western parts of the coastal plain, might not continue as open sands so far seaward.

The following table gives, where known, the approximate interval in feet from the top of one horizon to the top of the next:

WATER-HORIZONS IN STRATIGRAPHICAL ORDER, COMMENCING AT THE TOP.

YELLOW GRAVEL.		. . . . Neocene.
700-foot Atlantic City horizon.	Interval about 100 feet.	
800-foot Atlantic City horizon.	Interval about 150 feet.	
950-foot Atlantic City horizon.	Interval not yet known.	. . . . Eocene.
Lindenwold horizon.	Interval about 50 feet.	. . . . Cretaceous.
Marlton horizon.	Interval about 115 feet.	
Cropwell horizon.	Interval 125 to 150 feet.	
Woodbury-Wenonah horizon.	Interval about 70 feet.	
Sewell horizon.	Interval not yet determined.	
Raritan horizons. A group.		

The principal horizons near the coast in northern New Jersey are the Woodbury-Wenonah and the Cropwell. The southward increase in the depths of these horizons is shown by the following data:

Locality.	Cropwell Horizon.	Woodbury-Wenonah Horizon.
Asbury Park	400 feet.	525 feet.
Ocean Grove	400 feet.	525 feet.
Belmar	500 feet.	650 feet.
Sea Girt	600 feet.	735 feet.
Bay Head	710 feet.	885 feet.
Mantoloking	790 feet.	922 feet.

Both of these horizons are in the laminated sands (sands alternating with clays) forming the upper part of the Clay Marl formation. The Clay Marl is 275 feet thick, and is separated from the Triassic by 347 feet of Plastic (potters') Clay and lignite of the Raritan formation — the basal member of the Cretaceous.

The Water-Horizons of Long Island.

Long Island is almost as completely isolated geologically as it is geographically. The fact that its sedimentary formations do not outcrop on the mainland of Connecticut or New York makes it entirely impossible that they should derive water directly from the rainfall of those regions; and when we consider the massive structure of the underlying crystalline rocks, and still more the continuous barrier presented to the westward by the great trap-sheet forming the Palisades of the Hudson and extending south through Jersey City, Bergen Point and Staten Island to Perth Amboy in New Jersey, it becomes evident that it is equally impossible by deep subterranean flow.

Southwestward, the Cretaceous and Tertiary formations of Long Island are undoubtedly continuous with those of Staten Island and New Jersey; and with no barrier intervening, save the sea; but the movement of the ground-water along the strike of the strata for so great a distance is in the highest degree improbable. We must, therefore, conclude that the rain-water falling on Long Island is the only possible source of the fresh water contained in its strata.

The Raritan and Clay Marl formations are probably the only divisions of the Cretaceous represented on Staten and Long Islands, and the Clay Marl only imperfectly.

In New Jersey, where the Cretaceous strata outcrop wholly on the land, some of the sand and gravel layers are, as the preceding notes show, important water-horizons; in fact, a principal source of the artesian supplies. But on Long Island these coarse, water-bearing strata appear to be less persistent, and they outcrop mainly below sea-level. They thus lack an appreciable hydrostatic head; and if they were heavily drawn upon, the water might become brackish. In only three of the Long Island wells of which we have authentic records, is a satisfactory supply of water obtained from the Cretaceous beds. One of these is test well No. 25, of the Brooklyn Water Supply, and the other two are on Barren Island, in Jamaica Bay. The latter are flowing wells, yielding fifty gallons each per minute of excellent water from a stratum 30 feet thick of yellowish white coarse sand and fine gravel, with clay above and below. This is supposed to belong to the top of the Plastic Clay (Raritan), though possibly to the base of the Clay Marls (Matawan); and in the report of the State Geologist of New Jersey for 1896, it is stated that the water horizon opened by this well can probably be relied upon to supply fresh water to many of the beaches to the eastward along the southern coast of Long Island. It is also stated that the coarse white sand and gravel found in the Woodhaven well between 456 and 515 feet is probably the same bed as the water horizon at Barren Island (690–740 feet) and that it could probably be made to yield water at Woodhaven. The artesian well at Barnum Island (383 feet) is believed to end in the upper part of the Clay Marls. It affords but little water, and in spite of the few successful wells, there appears to be but little encouragement to extend borings or wells into the Cretaceous; but it does appear to be a matter of importance to discover by systematic borings the valleys which were eroded in the Cretaceous and subsequently filled by the gray sand and gravel series underlying the blue clay.

Omitting the Cretaceous, the formations of Long Island present, in a general view, two principal water-horizons, the gray gravel and sand below the blue clay, and the yellow gravel and sand above it. The blue clay and the gray gravel and sand normally underlying it, but also more or less interstratified with it, appear to be merely the coarser and finer parts of the same formation; and the fact that the gray gravel and sand in not a few instances are not water-bearing, is doubtless due in part to their lack of continuity where inclosed in the clay, and partly to the clay which they contain. Unlike the yellow gravel, the water-bearing quality of the gray gravel cannot be depended upon, but must be determined by trial.

Through the erosion of the blue clay, material was provided to form the limited beds of clay which are encountered here and there in the yellow gravel. These are found chiefly, as we should expect, in the lower part of the gravel, and in the south part of the island, as shown in borings Nos. 22 and 25, of the Brooklyn Water Works. They are probably rather rarely of particular value in determining the flow of water, since they are not likely to outcrop at the surface ; and we may suppose that in some cases they are so limited in area that water descending vertically through the gravel might flow over the edges of the intercepting lenses or patches of clay, and so descend to lower levels.

It is not improbable that erosion before the deposition of the yellow gravel has cut at some points entirely through the blue clay, so that the yellow gravel now rests directly upon the lower gravel or the Cretaceous strata. Such breaks in the blue clay would almost certainly have north-south trends ; and except along such lines, if they exist, the intake or catchment area of the lower or dark gray gravel is necessarily confined to the north shore and must be conceded to be rather limited. In other words, this lower gravel is a reservoir of great capacity and with a head of say 200 feet, which is now full of water. But if the reservoir were drawn upon heavily, the intake might prove insufficient to keep it full. An important consideration in this connection is that the intake or outcrop of this gravel crosses all of the harbors between Brooklyn and Eaton's Neck ; while east of Eaton's Neck it is wholly under the sea, suggesting the possibility that if subjected to large drafts it might in time yield brackish water, at least at some points. The intake or catchment area of the upper gravel, on the contrary, is from 10 to 15 miles wide ; and since this gravel averages at least 100 feet in depth, its store of water would seem to be practically inexhaustible, for the rainfall promptly sinks into the gravel with very little loss by either evaporation or surface drainage. Again, the normal intake of the lower gravel being on the north side of the island where the strata are so greatly disturbed, it is by no means certain that the flow would be wholly or mainly to the south.

The sedimentary formations of Long Island are not now exposed on the north shore of the Sound, and it is probable that, except for the drift and post-glacial silting, the crystalline rocks form the immediate floor of the Sound over its entire northern slope, only the abrupt southern slope consisting of the Cretaceous and Tertiary strata.

The highly disturbed condition of the strata on the north side of the island, and the infrequency of satisfactory outcrops, makes the construction of an accurate or detailed section impossible. Another very uncertain factor is introduced by the strong erosion of both the Cretaceous and Tertiary clays before the deposition over them of the water-bearing gravels. This cause of irregularity probably extends quite across the island, and it is for the determination of these erosion hollows and the great depths of gravel filling them, that systematic borings are especially needed.

The abruptness of the north shore, and the disturbed condition of the strata, which often dip to the north, make it impossible, also, to attach much importance to the portion of either gravel-horizon north of the moraine. The yellow gravel is naturally the most disturbed, but it also has a large catchment area, which is almost wholly above sea-level, while the lower gravel, although quite certainly less disturbed and dipping quite steadily to the south, has a relatively limited catchment area, and that is largely submarine. The water in the lower gravel, having no natural outlet, must be essentially stagnant, and so remain until tapped by deep wells along the southern shore. This fact, together with the abundance of wood and other carbonaceous matter, and of marcasite (iron sulphide), affords an explanation of the comparatively stale and mineralized character of this water.

The Bethpage and West Deer Park ridge of Tertiary clay greatly narrows the plain of yellow gravel, and must accentuate its basal slope. This clay, which appears again near Lake Ronkonkoma, probably attains a high level near the southern margin of the moraine from Bethpage eastward. Therefore, little reliance should be placed upon the yellow gravel north of this line; and borings are urgently needed to test the thickness of the yellow gravel and the depth and gradient of the water-level in it, before plans for the development of the Brookhaven watershed are fully matured.

The following list of Artesian wells in Long Island is not exhaustive, embracing only those of most particular geological interest. The wells designated by number are test wells of the Brooklyn Water

Works. In tabulating the borings it has been found advantageous to generalize the data in order to bring out more clearly the main geological facts. The first four borings in the tabulated list (Jamaica, Jericho, Hollis and Port Eaton) represent the northern edge of the field, while all the others are near the southern margin and mostly near the conduit line where it crosses the Hempstead Plains.

a. The Cretaceous in this well consists, downward, of gray clay with wood, 19 feet; fine sand with wood, 36 feet; fine sand and clay, with wood, 11 feet; fine sand with wood, 38 feet = 104 feet.

b. The blue clay is described as sandy clays; the gray gravel is really a fine gray quicksand; the Cretaceous consists of alternating beds of sand and clay with some lignite, in beds from 5 to 50 feet thick, representing both the Matawan and Raritan; the well penetrated 21 feet into the gneiss.

c. The 104 feet of dark sand and gravel is probably in part Cretaceous.

d. The gray gravel is probably included with the Cretaceous.

e. The yellow gravel is all sand; the blue clay is described as gray clay with wood and pyrite; the gray gravel as gray sand with wood; and the Cretaceous as clay and sand with wood.

f. The blue clay and gray gravel may be included in the 276 feet of alternating sand and clay, with wood.

g. Two driven wells near Barnum's Island, 97 and 194 feet deep, failed to find the bed of blue clay, which is 56 feet thick in the artesian well. This indicates local erosion of the blue clay during the deposition of the yellow gravel. The Cretaceous of this well is believed to be the Matawan or Clay Marls. It contains much fossil wood in the form of lignite. The 480 feet of Cretaceous strata in the Barren Island wells represent, according to Woolman, both the Matawan and the Raritan.

h. Clay in the yellow gravel from 56 to 67 feet; the blue clay consists of sand and clay, with wood; the gray gravel is not distinctly developed; the Cretaceous consists of numerous alternations of clay, sand and gravel, with wood and pyrite. No water below the yellow gravel except a little between 329.6 and 338.6 feet.

i. Clay in the yellow gravel from 52 to 74 feet; the blue clay and Cretaceous are essentially the same as in No. 22.

j. Clay in the yellow gravel from 68 to 78 feet.

k. Clay in the yellow gravel from 53.8 to 61.8 feet; the blue

ARTESIAN WELLS IN LONG ISLAND.

NUMBER AND LOCATION.	Elevation of surface.	LAFAYETTE.	CHESAPEAKE.		Cretaceous.	Total depth.	REMARKS.
		Yellow gravel.	Blue clay.	Gray gravel.			
No. 11, Jamaica . . .	19.2	95	95	8	..	198	Water in gravels.
Jericho	?	147	51	12	..	210	Drift 51 ft.; yellow gravel 96 ft.
No. 6, Hollis Sta. (*a*) .	58.6	302	...	...	104	406	No water below yellow gravel.
Port Eaton	4	265	...	...	..	265	Salt water to 205 ft.; fresh water at 263 ft.
East New York . . .	...	149	...	...	..	149	Ended in sandy clay with lignite.
Woodhaven. (*b*) . . .	35.6	213	145	59	139	577	Ended in gneiss; little water.
No. 5, Ridgewood . . .	61.8	193	87	4	..	284	Water in gravels.
No. 4, 1¼ miles S. E. from No. 5	8.6	117.4	13	9	..	139.4	Water in gravels.
Baisley's	6.7	106	50	44	..	200	Water in gravels.
No. 1, S. of Baisley Pond.	5.5	88	53	14	..	155	Water in gravels.
No. 4 (*a*), Jameco . . .	1.7	79	58	13	..	150	Water in gravels.
No. 2, ⅓ mile E. from No. 1. (*c*)	7.4	84	69	104	..	257	Water in gravels.
No. 3, ½ mile E. from No. 2	9.8	87	115	75	..	277	No water below yellow gravel.
No. 8, bet. Nos. 3 and 7.	10	72	139	84	..	295	No water below yellow gravel.
No. 7, W. of Springfield Sta. (*d*)	16	65	111	...	243	419	No water below yellow gravel.
No. 9, S. of Springfield Sta. (*e*)	10.3	110	20	16	125	271	No water below yellow gravel.
No. 12, W. of Rosedale Sta. (*f*)	18	130	...	...	276	406	No water below yellow gravel.
No. 10, N. E. of Springfield Sta.	27	89	5	118	145	357	No water below yellow gravel.
Barren Island	High tide.	260	...	...	480	740	Two wells; 50 gallons each per minute.
Barnum's Island. (*g*) . .	3 (?)	70	56	42	215	383	No water.
Fenhurst	...	54	46	57	..	157	Four wells; flow largely.
No. 22, E. of Valley Stream. (*h*)	17.4	82	87	...	201	370	No water below yellow gravel.
No. 23, near Merrick Sta. (*i*)	16.7	78	107	...	205	390	No water below yellow gravel.
No. 24, near No. 23. (*j*).	16	78	122	...	..	200	....
No. 25, at Watts Pond Sta. (*k*)	8 2	95	89	...	147	331	Sands are water-bearing.

clay consists of sand and gravel, 35 feet, and clay 54 feet; and the Cretaceous consists of alternating clay, sand and gravel, with wood.

In studying these borings, the erosion of the blue clay before and during the deposition of the yellow gravel over it demands particular attention. A valley in the blue clay is thus clearly shown by borings Nos. 9 and 12; while in the Hollis well (No. 6), and the Barren Island wells, erosion has cut entirely through the blue clay and the underlying gravel, so that the yellow gravel rests directly upon the Cretaceous beds. In this connection the gray gravel and sand normally underlying the blue clay are to be counted as a part of it, and in some cases, perhaps, where the clay is wanting, as its full equivalent.

The data are obviously insufficient to define satisfactorily all the erosion troughs or valleys in either the Tertiary or Cretaceous clays; and the need of a systematic exploration of the coastal plain by wash drill borings is apparent.

The deep well at Port Eaton on the north shore is of special interest. The water-level is at the surface, which is only 4 feet above sea-level. The well is 265 feet deep, and *wholly* in the yellow gravel and sand. Salt water was obtained at intervals to 205 feet, and fresh water was first found at 263 feet.

This is a most striking instance of the disturbance and displacement of the strata by the ice-sheet. The ice is estimated to have been anywhere from a thousand feet to a mile in thickness; and no doubt its dead (vertical) weight as well as its thrust was an important factor in squeezing out the blue clay and depressing the yellow gravel and sand. The dip of the beds must be to the north here, and the great depth at which the first fresh water was found would seem to show that the movement of the ground water is northward for a considerable distance back from the shore. This well, therefore, strengthens the general conclusion that the northern watershed cannot be depended upon to furnish water to the yellow gravel south of the moraine.

That the yellow gravel is continuous under, or underlies, the moraine, there can be, as stated, no reasonable doubt; and it is probably the chief source of the water afforded by wells located on the moraine, as in Brooklyn and Long Island City, where the records show that the wells pass through from 50 to 150 feet or more of bowlder-clay to a coarse, clean gravel yielding good and copious supplies of water.

The details of a few of these wells are quoted from the New Jersey Reports for 1897 and 1898:

Five wells in the 26th ward of Brooklyn, gave: loam and fine sand, 10 feet; water-bearing gravel, 25 feet; clay, 1 foot; sand and gravel, 35 to 65 feet; and then clay (probably the blue clay). The collective yield of these wells is 2,000,000 gallons in 24 hours. The yellow gravel is, evidently, the surface formation here. The well at Malcolm's Brewery, in Brooklyn, 62 feet deep, presents similar conditions.

Four wells in Long Island City, 100 to 135 feet deep, passed through bowlder-clay to a coarse gravel which yields from 75 to 125 gallons of good water per minute. This is probably the yellow gravel beneath the moraine.

In the following wells the yellow gravel is wanting, having, apparently, been scraped away by the ice-sheet:

ARTESIAN WELL IN CALVARY CEMETERY, BROOKLYN.

Drift, (Moraine)	139 feet.
Greenish earth (Glauconitic ?) Cretaceous	39 feet.
White clay	4 feet.
Gneiss	400 feet.
	582 feet.

ARTESIAN WELL OF THE NASSAU GAS-LIGHT COMPANY, WILLIAMSBURG.

Drift, (Moraine)	75 feet.
Blue clay with pebbles	27 feet.
Oyster shells	0.5 feet.
	102.5 feet.